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Do quiet standing centre of pressure measures within specific frequencies differ based on ability to recover balance in individuals with stroke?

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HIGHLIGHTS

- Standing centre of pressure signals from individuals with stroke were decomposed.
- Individuals with poor ability to recover balance showed impaired standing control.
- This technique may have potential to assess ability to recover balance post-stroke.

ABSTRACT

Objective: To determine whether quiet standing measures at specific frequency levels (representative of reactive control) differed between individuals with stroke based on their ability to recover balance (Failed or Successful Responses to external perturbations).
Methods: Individuals with stroke completed a clinical assessment, including 30 s of quiet standing and lean-and-release postural perturbations, at admission to in-patient rehabilitation. Quiet standing centre of pressure (COP) signals were calculated and discrete wavelet decomposition was performed. Net COP amplitude, between-limb synchronization, and ratios of individual-limb COP were determined for each frequency level of interest, and for the non-decomposed signal (all frequency levels). Outcome measures were compared between individuals who exhibited Failed and Successful Responses during (a) unconstrained and (b) encouraged-use lean-and-release trials.
Results: Individuals with Failed Responses during the unconstrained lean-and-release trials displayed greater net COP amplitude than those with Successful Responses, specifically within a frequency range of 0.40–3.20 Hz.
Conclusions: Reduced ability to recover balance among individuals with stroke may be reflected in impaired reactive control of quiet standing.
Significance: These results provide insight into the mechanism by which reactive control of quiet standing is impaired in individuals with stroke, and may inform assessment and rehabilitation strategies for post-stroke reactive balance control.

1. Introduction

Falls risk is increased in individuals with stroke compared to age-matched healthy individuals, and falls are one of the most frequent complications experienced during post-stroke recovery (Batchelor et al., 2012). Up to 73% of individuals with stroke fall following their return to community living after discharge from

Abbreviations: CMSA, Chedoke-McMaster Stroke Assessment; COM, centre of mass; COP, centre of pressure; NIHSS, National Institutes of Health Stroke Scale; RMS, root mean square.

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rehabilitation (Weerdesteyn et al., 2008), and individuals with stroke are 2–4 times more likely to suffer a fall-related injury compared to age-matched controls (O'Loughlin et al., 1993; Graafmans et al., 1996; Jørgensen et al., 2002). Falls occur when an individual fails to recover from a loss of balance (Maki and McIlroy, 1996), which could potentially result from either external or internal postural perturbations.

A step is one of several possible responses to postural perturbations. Stepping allows the individual to regain stability by re-capturing the moving centre of mass (COM) within the base of support (Maki and McIlroy, 1997, 2005; Maki et al., 2003). The ability to execute compensatory steps following a perturbation is critical in maintaining balance and mobility (Maki and McIlroy, 1997) and in preventing falls (Holliday et al., 1990; Hyndman et al., 2002). Stepping reactions are often impaired in individuals with stroke, such that steps in response to a perturbation tend to be characterized by an increased need for external assistance, inability to step with either limb, and/or increased occurrence of multiple-step responses (Lakhani et al., 2011; Inness et al., 2014). Furthermore, impaired stepping in individuals with stroke has been related to the occurrence of falls during (Mansfield et al., 2013) and following (Mansfield et al., 2015) discharge from in-patient rehabilitation.

The control of quiet standing is also impaired post-stroke, such that individuals with stroke exhibit greater net centre of pressure (COP) amplitude relative to healthy controls (Mansfield et al., 2011). In addition, there is a trend towards reduced temporal synchronization between the COP of the left and right limbs among individuals with stroke compared to healthy controls (Mansfield et al., 2011). Increased COP amplitude in quiet standing is associated with increased falls risk in older adults (Maki et al., 1994). Similarly, reduced between-limb synchronization is related to increased falls risk during (Mansfield et al., 2012) and following discharge from in-patient rehabilitation (Mansfield et al., 2015) among individuals with stroke.

Previous studies have examined all frequencies present in the COP time series collectively (Mansfield et al., 2011, 2012, 2015), providing a global indication of quiet standing control (Singer and Mochizuki, 2015). However, previous models have suggested two main frequency components within the COP signal, above and below approximately 0.4 Hz (Winter et al., 1998; Zatsiorsky and Duarte, 1999, 2000). The lower frequency components may represent an anticipatory control mechanism, indicative of COM dynamics, exploratory COP migrations, or errors in state estimation (Winter et al., 1998; Latash et al., 2003; Kiemel et al., 2006; Carpenter et al., 2010); while the higher frequency components may be representative of reactive control, specifically balance corrections executed in response to transient instability (Paillex and So, 2003; Singer and Mochizuki, 2015). Frequency decomposition of the COP signal may provide more detailed information regarding reactive versus anticipatory control of quiet standing in individuals with stroke (Singer and Mochizuki, 2015), and insight into mechanisms by which reactive control of quiet standing is impaired, and fall risk subsequently increased, in this population.

To our knowledge, no study to date has examined the reactive control of quiet standing as a function of ability to recover balance in individuals with stroke. This study aimed to determine whether quiet standing measures at specific frequency levels within the COP signal differed based on ability to recover balance in individuals with stroke. The same measures, calculated for the non-decomposed COP signal (all frequency levels), were also compared between groups. It was hypothesized that compared to those with successful balance recovery reactions, individuals with failed reactions would exhibit greater COP amplitude, reduced between-limb synchronization, and ratios between the individual-limb COP amplitudes that were further from 0.50; these differences would be identified at frequencies representative of reactive control (>0.4 Hz), but not those representative of anticipatory control (<0.4 Hz).

2. Methods

2.1. Participants

This study consisted of a retrospective analysis of data from individuals with stroke who were enrolled in an in-patient stroke rehabilitation program between October 2009 and September 2012. For inclusion in the analysis, a clinical assessment must have been conducted at admission by a physiotherapist (part of routine care), during which participants must have completed a 30 s trial of eyes-open quiet standing, as well as five 'unconstrained' trials with a lean-and-release system to assess ability to recover balance (see Section 2.2). These criteria were met by 84 of 512 individuals (16%). All procedures were approved by the Toronto Rehabilitation Institute Research Ethics Board (approval number: TRI-REB #10-046) with a waiver of patient consent approved for the purpose of the review.

2.2. Assessments

2.2.1. Demographic information

Participants' hospital charts were used to determine sex, age, time post-stroke, affected side of the body, National Institutes of Health Stroke Scale (NIHSS) score, and Chedoke-McMaster Stroke Assessment (CMSA) foot score for the affected side of the body (Fig. 1). These variables were assessed as potential covariates in the analysis (see Section 2.4). Stroke type and presence/absence of peripheral neuropathy, vestibular conditions, visual field deficit, and neglect were also collected from hospital charts to characterize the study sample (Table 1).

2.2.2. Quiet standing

As part of the clinical assessment, each participant performed one 30 s quiet standing trial with the eyes open. Ground reaction forces were recorded from two adjacent force plates (Advanced Mechanical Technology, Inc., Watertown, USA). Participants stood with one foot positioned on each plate, with a template used to ensure standardized foot position (McIlroy and Maki, 1997). No further instructions regarding weight bearing were provided. Force plate data were sampled at 256 Hz. COP signals for the quiet standing trials were calculated offline. Metrics determined from these signals were used as dependent variables in the analysis (see Sections 2.3 and 2.4).

2.2.3. Reactive stepping

Participants also completed a lean-and-release test to assess ability to recovery balance (Mansfield et al., 2013). Participants wore a safety harness connected to an overhead frame to protect against a fall. A harness around the participant's trunk was attached by a cable to a support beam behind the participant. At the beginning of each trial, the same template as described in Section 2.2.2 (McIlroy and Maki, 1997) was used to ensure that the feet were in a standardized position with one foot on each of two force plates. The participant then leaned against the release cable such that it supported approximately 10% of body weight. The cable was released at an unpredictable time, requiring the participant to take at least one step to prevent a fall. A third force plate was positioned in front of the other two force plates, such that participants generally stepped forward onto the third force plate. Ground reaction force data were collected throughout the lean-and-release trials as standard practice for the clinical balance assessment protocol. However, these data were not used for the purpose of the current analysis.